Report on W/SciFi and W/Shashlik Calorimeter R&D

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BNL

EIC R&D Committee Meeting
July 26, 2018

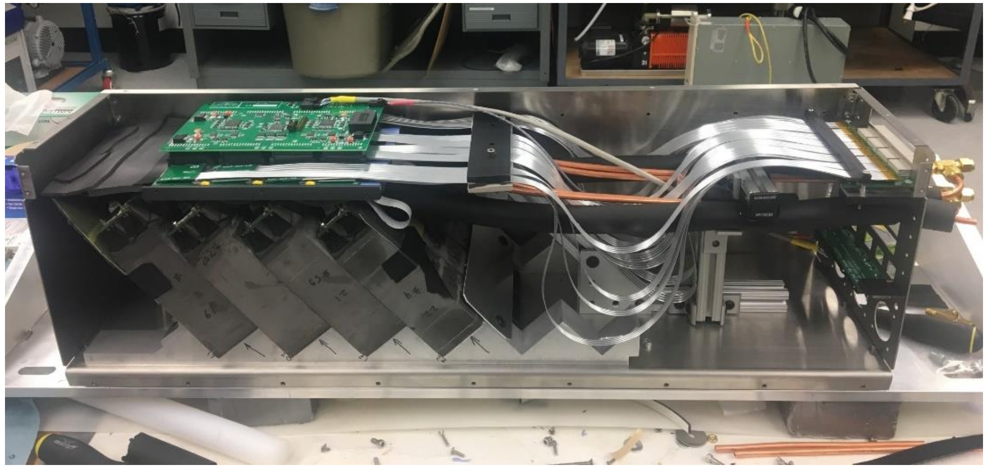
Status of the sPHENIX EMCAL (FYI)

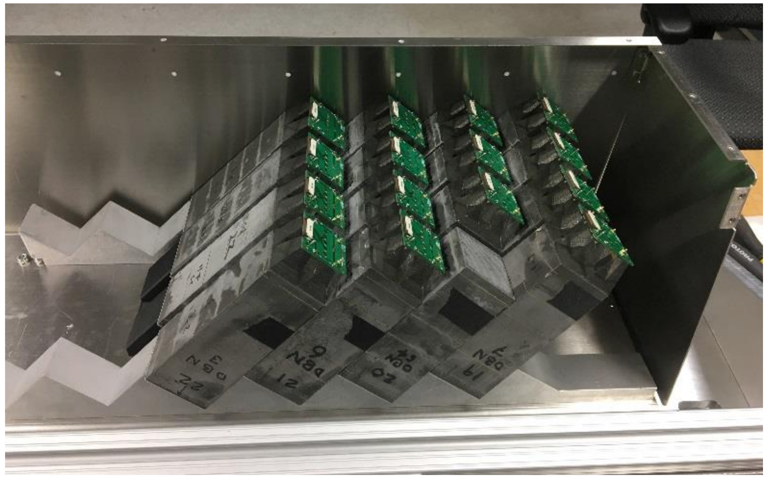
- sPHENIX passed its CD-1 Review in May and is getting strong encouragement to move forward quickly from both BNL Lab Management and DOE.
- Completed a series of beam tests with the V2.1 EMCAL prototype at Fermilab between February and May 2018.
- Effort is now under way to build a preproduction prototype of a complete sPHENIX EMCAL sector.
- A Retreat was held on July 12th to discuss the evolution of the sPHENIX detector to an EIC detector in the I8 Intersection Region at RHIC.

V2.1 EMCAL Prototype

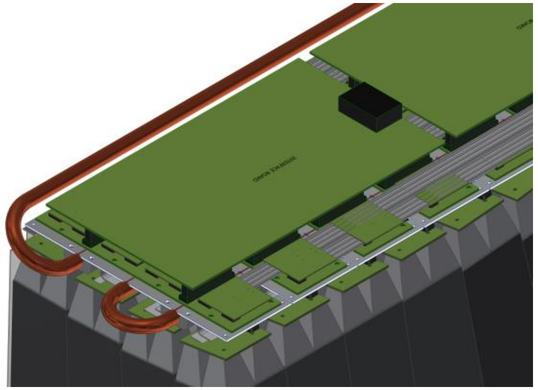
Incorporates actual sector design for mechanical support and enclosure, electronics, cables and cooling

2D projective blocks represent η ~ 0.9

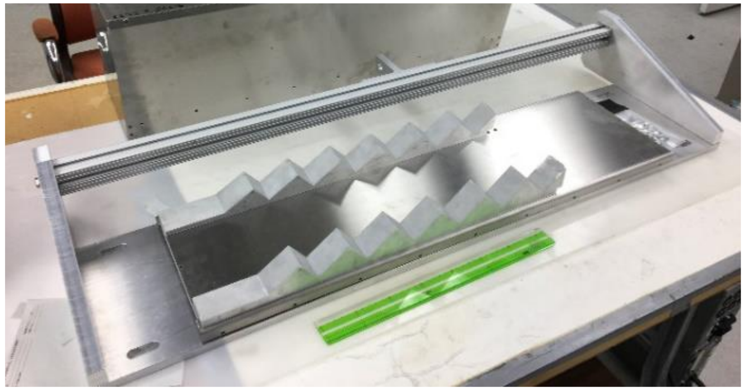




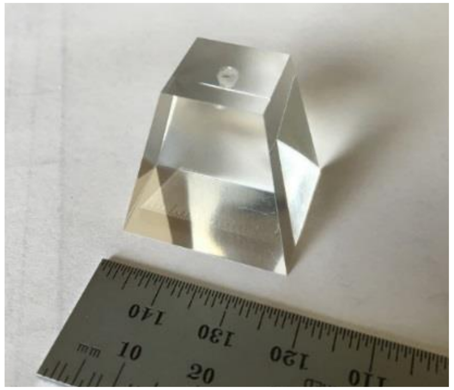
4x4 blocks
8x8 towers
256 SiPMs



Liquid cooling



Sawtooth support

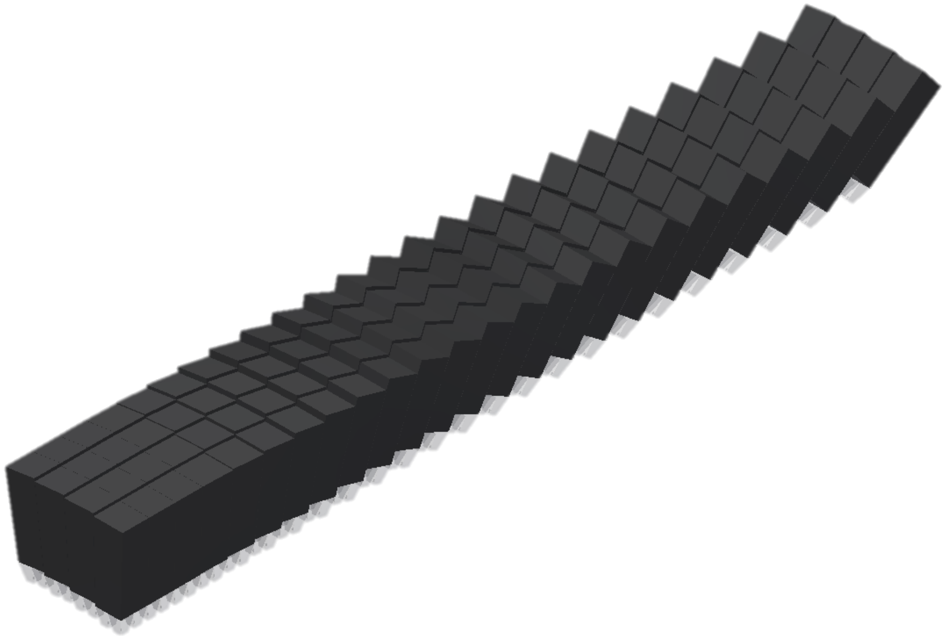


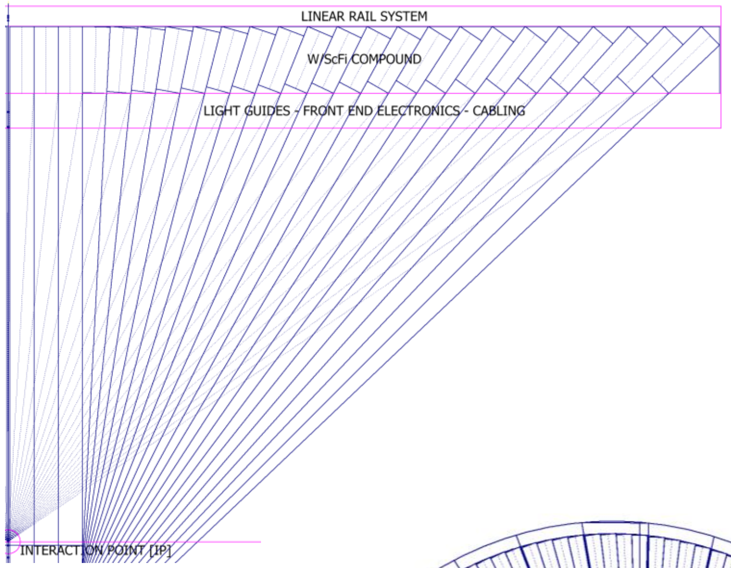
Light guides manufactured by optical quality injection molding

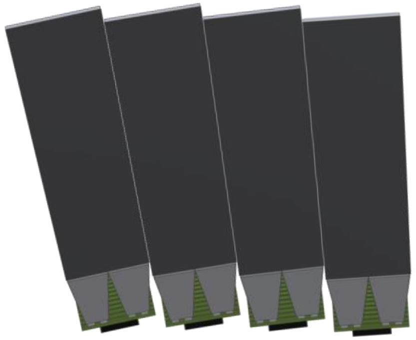
Projectivity

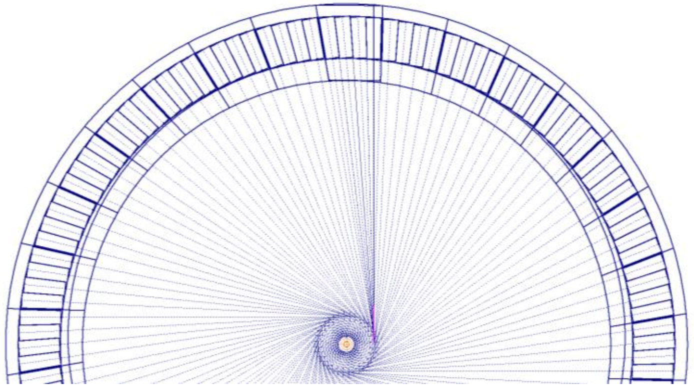
The absorber blocks are projective but the calorimeter is not

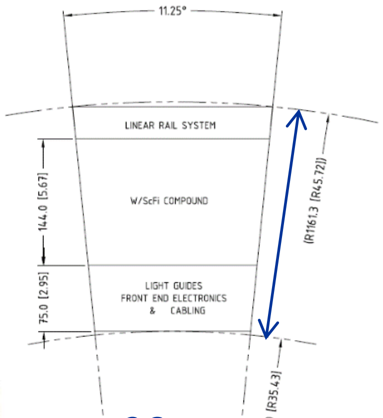
The blocks are tilted by ~ 9°
(164 mrad in η and 157 mrad in ϕ)







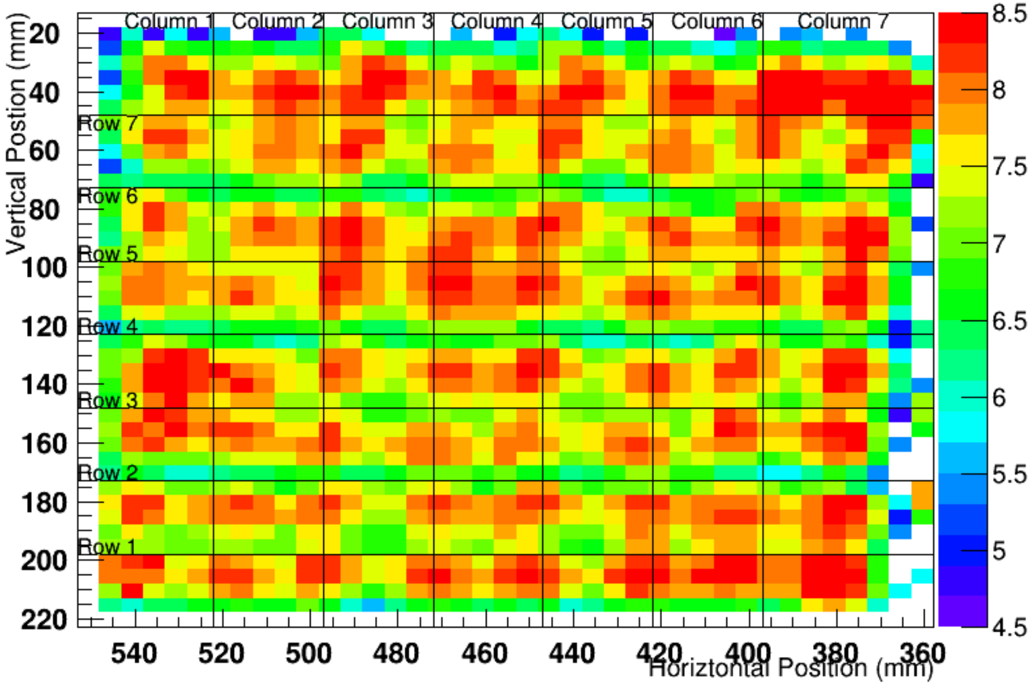




26 cm
radial space

Uniformity of response

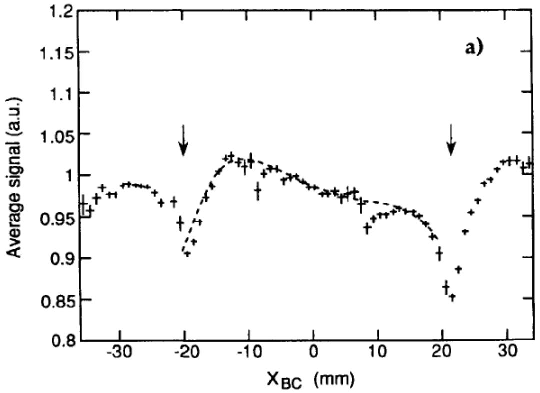
8 GeV electrons - sPHENIX tilted position



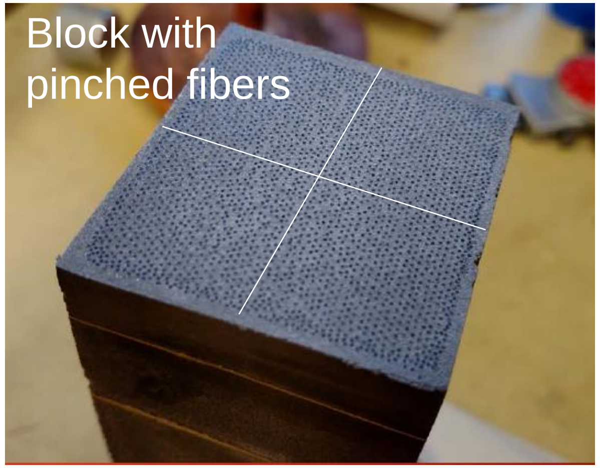
Energy response measured over the entire 8x8 towers of the prototype (2018 beam test)

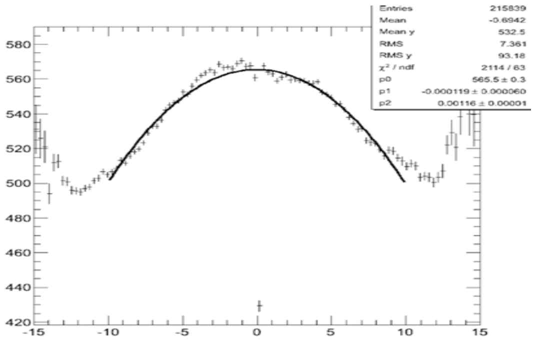
Energy resolution: $\sigma_E/E \sim 16\%/\sqrt{E} \oplus 3.2\%$

Non-uniformities are inherent in the SPACAL design, especially with limited photocathide coverage.

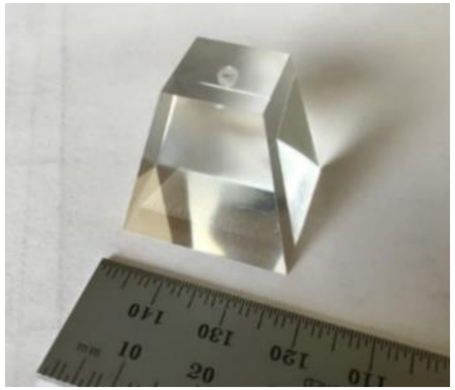


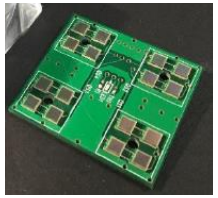
Original SPACAL (Wigmans 1995)





2014 Test Beam Data (UCLA)

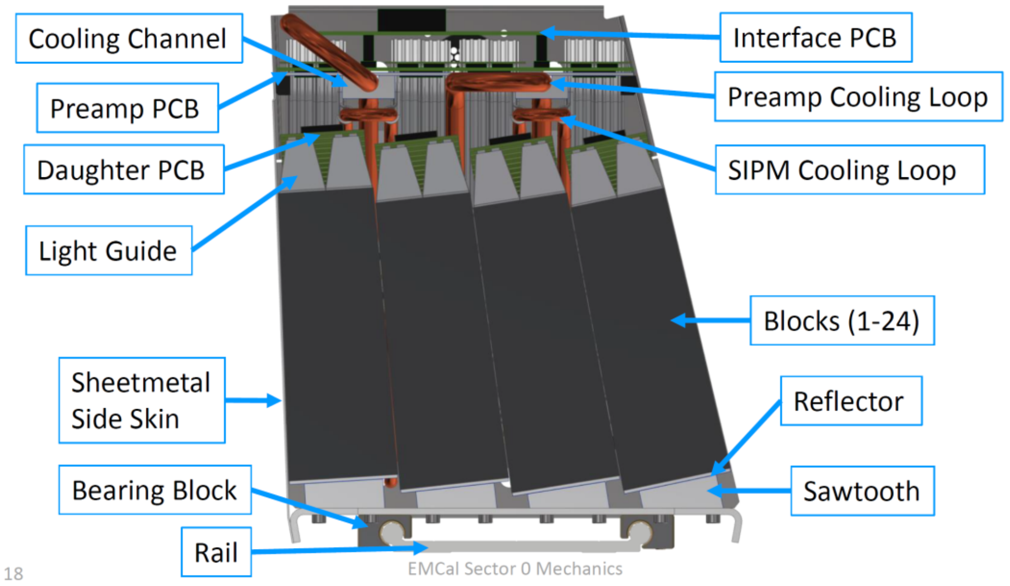




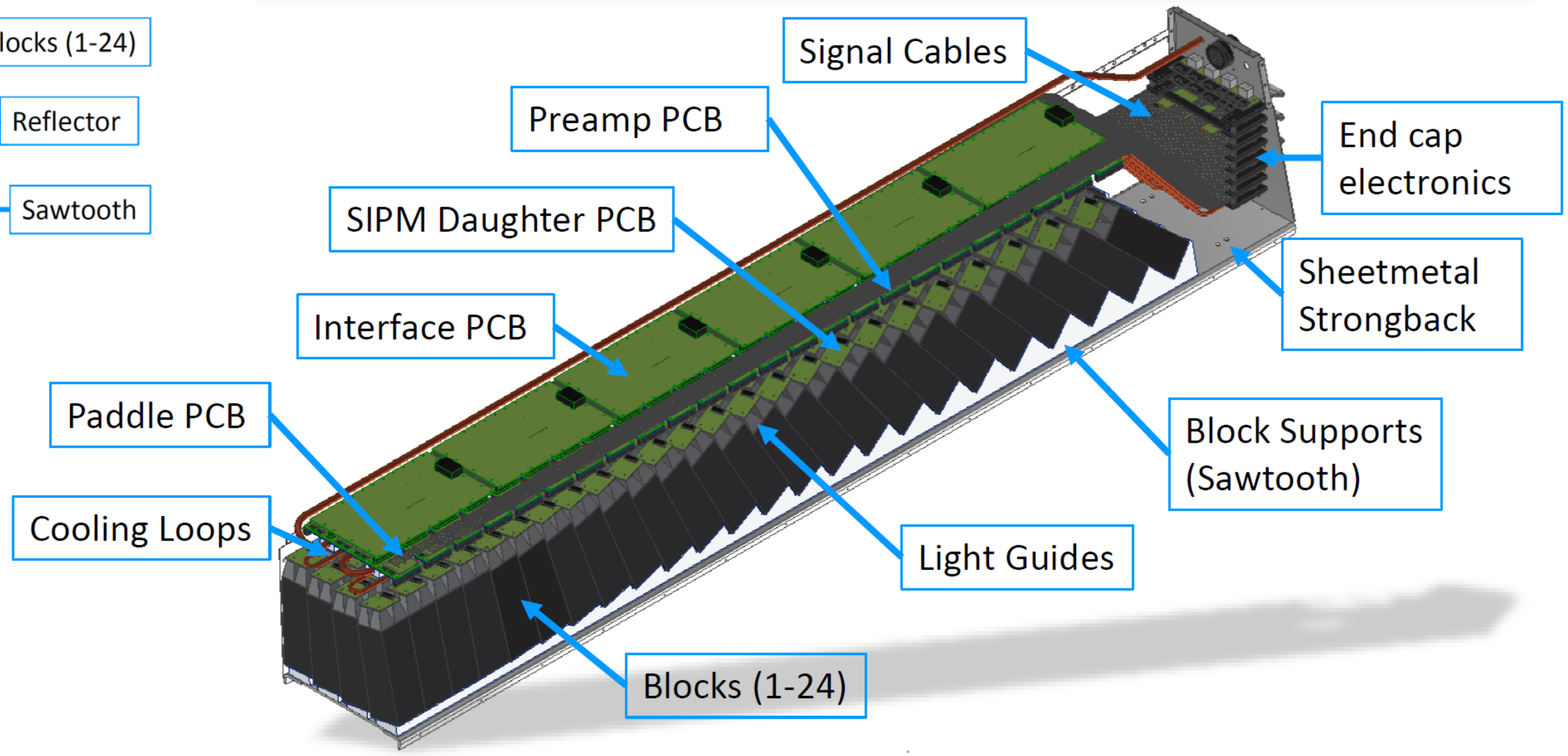
4 SiPMs per tower

Light guides limited to 1” in height due to space constraints

Construction of first preproduction prototype sector



Sector 0

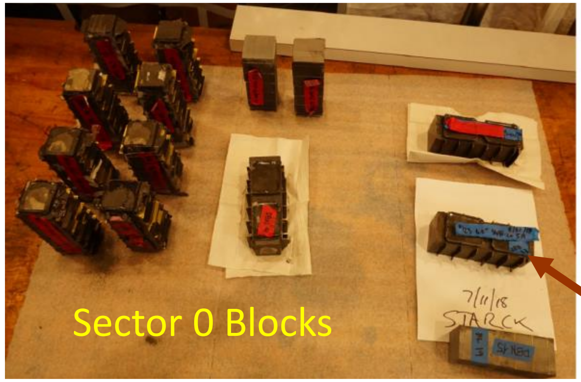


Incorporates full system design of electronics, cables & cooling

Production of preproduction blocks at UIUC

Loomis Physics Lab Machine Shop and Assembly Area at UIUC

sPHENIX production tent



Space also includes dedicated machine shop and additional storage

Some blocks being made using powder from a new supplier (Starck)

Summary of ePHENIX Retreat

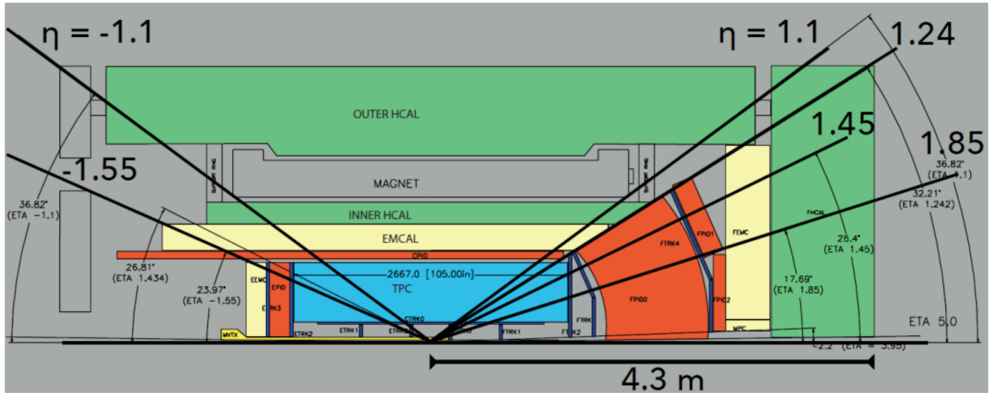
Purpose was to discuss how to design and build a multipurpose detector for EIC in RHIC IR 1008 reusing as many components from sPHENIX as possible

EIC-SPHENIX ELECTROMAGNETIC CALORIMETERS COVER -4 < ETA < 4. 7

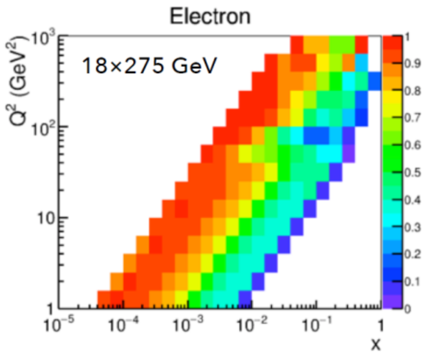
$-4 < \eta < -1.55$	$PbWO_4$	2 cm x 2 cm	$\frac{2.5\%}{\sqrt{E}} \oplus 1\%$
$-1.55 < \eta < 1.24$	W-SciFi	0.025 x 0.025	$\frac{16\%}{\sqrt{E}} \oplus 5\%$
$1.24 < \eta < 4$	PbScint	5.5 cm x 5.5 cm	$\frac{8\%}{\sqrt{E}} \oplus 2\%$

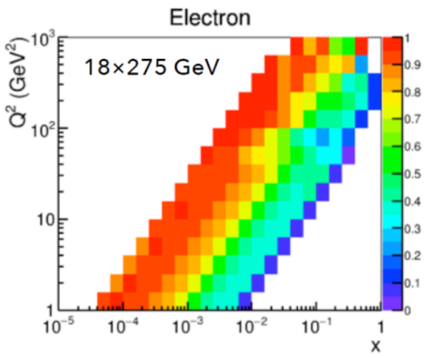
Hadron calorimeters:

$-1.1 < \eta < 1.1$	Fe Scint + Steel Scint	0.1 x 0.1	$\frac{81\%}{\sqrt{E}} \oplus 12\%$
$-1.24 < \eta < 5$	Fe Scint	10 cm x 10 cm	$\frac{70\%}{\sqrt{E}}$



$$\frac{\sigma_E}{E} = \frac{16\%}{\sqrt{E}} \oplus 5\%$$





$$\frac{\sigma_E}{E} = \frac{10\%}{\sqrt{E}} \oplus 1\%$$

S.Bazilevsky (BNL)

New LOI to be submitted by Sept 30, 2018

N.Feege (SBU) & C. Aidala (UMich)

Main Question: What physics drives the energy resolution requirements and how does the resolution impact the physics measurements ?

R&D on W/Shashlik Calorimetry

- Technology was proposed last year as a possible alternative to a W/SciFi calorimeter for EIC.
- Committee correctly noted that the shashlik technology has been around for many years and has already been shown to be able to achieve good energy resolution and uniformity.
- Recommended a survey of the currently operating shashlik calorimeters and that a Monte Carlo study be carried out.
- Did not recommend funding at that time, but that the proponents work with the eRD1 collaboration to move forward.

Why study this technology for EIC ?

- Uniformity of response is difficult to achieve with a ***compact*** W/SciFi design.
- Main issue is light collection uniformity.
- A compact shashlik offers the ***possibility*** of improving the light collection uniformity due to the short light path to the WLS fibers.
- Availability of low cost SiPMs allows reading out each fiber individually. This allows determining the position of a shower even within a tower.

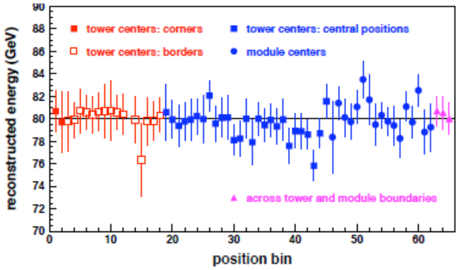
Uniformity of Achieved with a Pb/Sci Shashlik

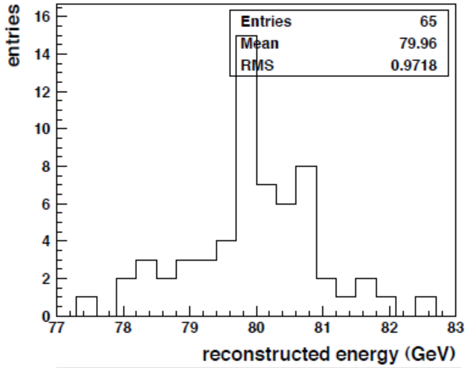
ALICE Pb/Sci Shashlik EMCAL

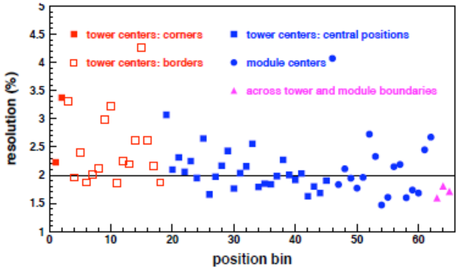
Table 2.1: The EMCal Physical Parameters.

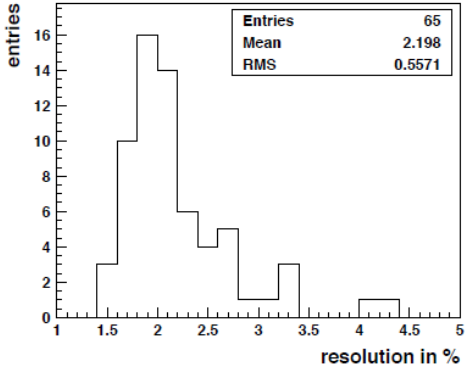
Quantity	Value
Tower Size (at η=0)	$\sim$6.0 $\times$ $\sim$6.0 $\times$ 24.6 cm (active)
Tower Size	$\Delta\phi \times \Delta\eta = 0.0143 \times 0.0143$
Sampling Ratio	1.44 mm Pb / 1.76 mm Scintillator
Number of Layers	77
Effective Radiation Length X_o	12.3 mm
Effective Moliere Radius R_M	3.20 cm
Effective Density	5.68 g/cm^2
Sampling Fraction	10.5
Number of Radiation Lengths	20.1
Number of Towers	12,288
Number of Modules	3072
Number of Super Modules	10 full size, 2 one-third size
Weight of Super Module	$\sim$7.7 metric tons (full size)
Total Coverage	$\Delta\phi = 107^o$, -0.7 < η < 0.7

Uniformity of energy resolution with 80 GeV electrons

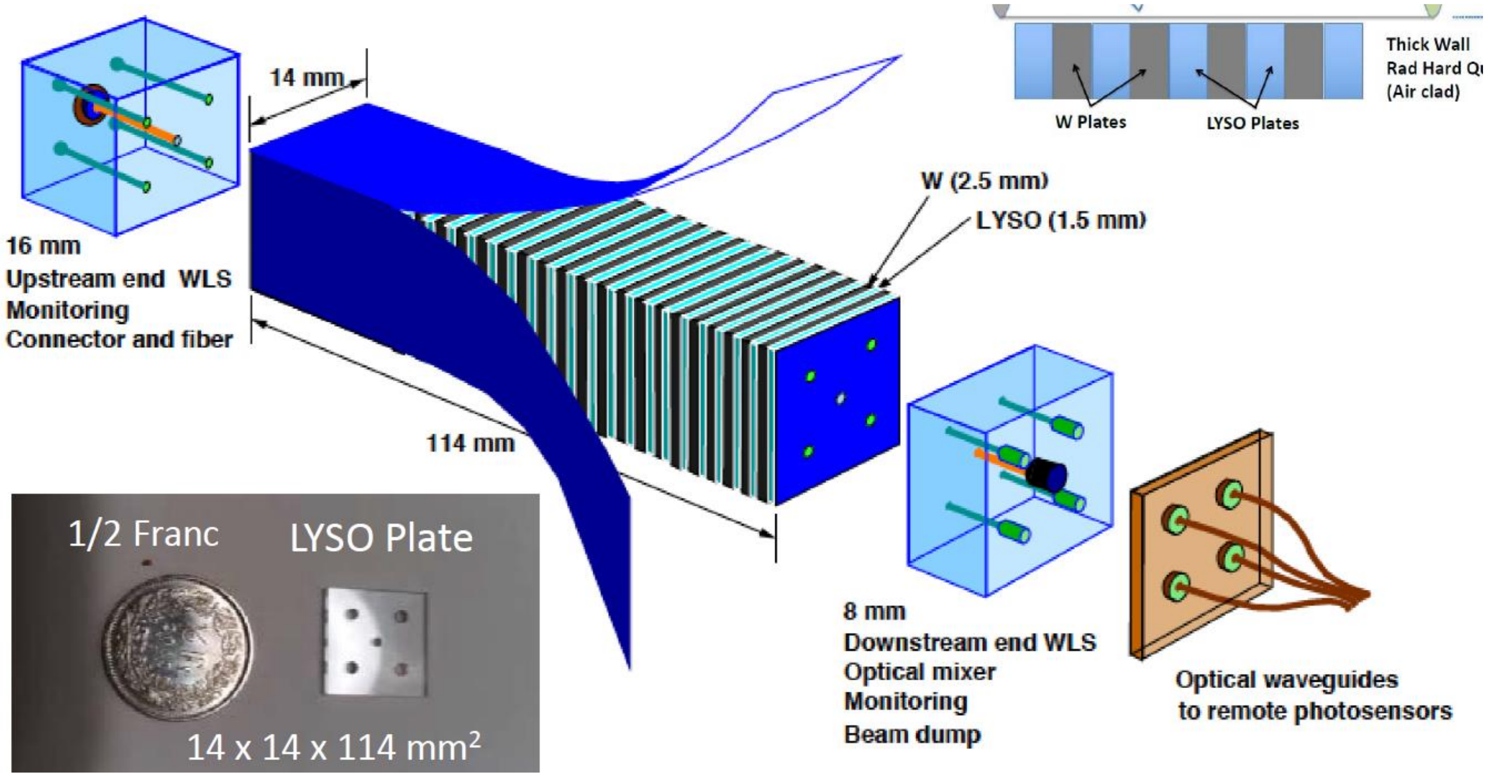


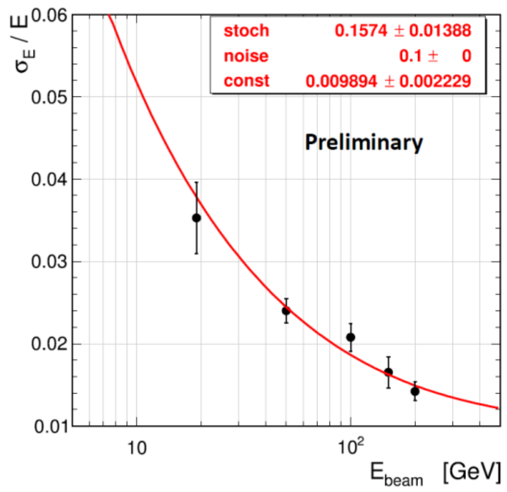


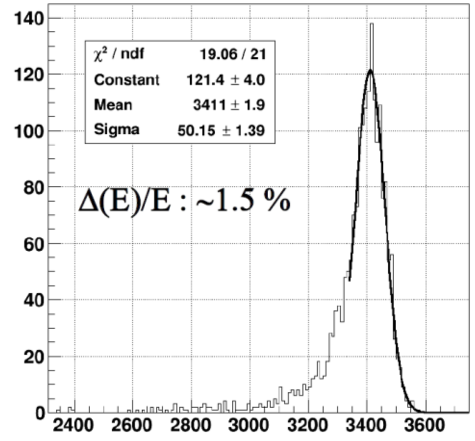


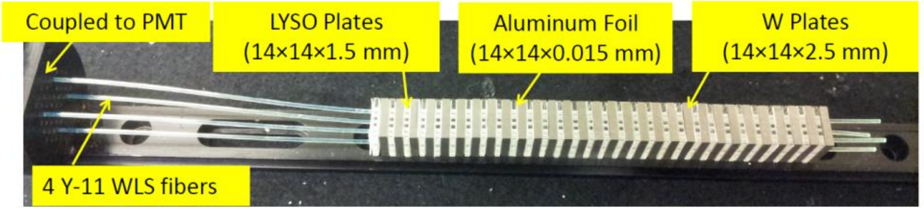


Study of a W/LYSO calorimeter module for CMS







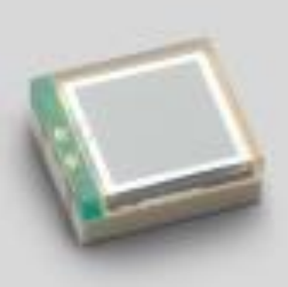


- WLS fibers coupled together and read out as a single tower.
- Looking at only high energies.
- Main purpose was to survive radiation damage.

R-Y. Zhu (Caltech)

New SiPMs for Calorimetry

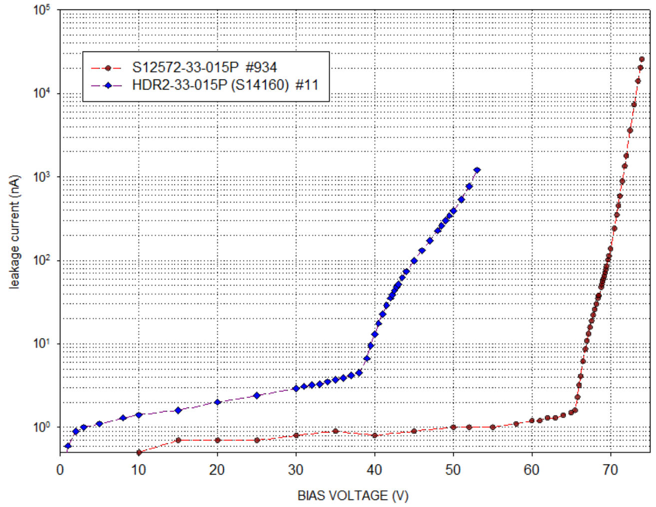
Hamamatsu



Improved version of S12572 used in sPHENIX calorimeter is now available (similar to the Hamamatsu S14160)

3x3 mm^3
40K 15 μm pixels

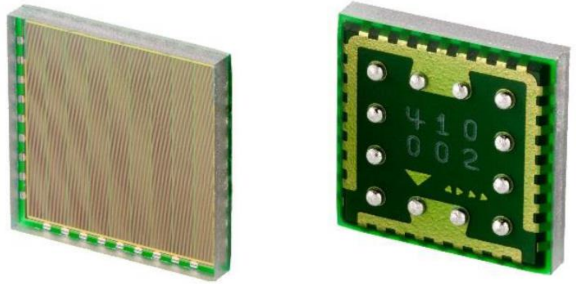
- Incorporates deep optical trenches between micropixels
- Reduces photon feedback
- Lower crosstalk
- Lower afterpulsing
- Lower noise
- Lower Vop



We've obtained 16 of the new HPK MPPCs (8 at BNL and 8 at UCLA) and are in the process of characterizing them

KETEK

SiPM – Silicon Photomultiplier
PM3315-WB / PM3325-WB



WB Series in new Wafer Level Package

3x3 mm^3
38K 15 μm pixels

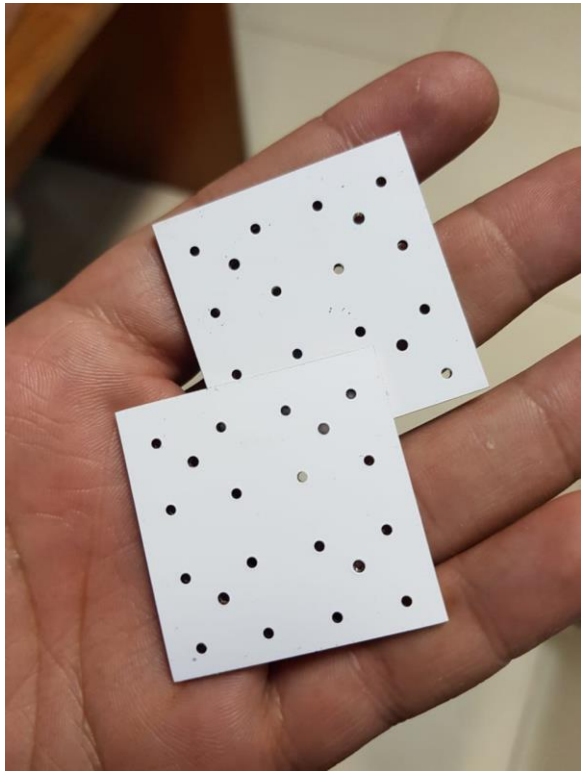
Lower initial noise should lead to better radiation tolerance

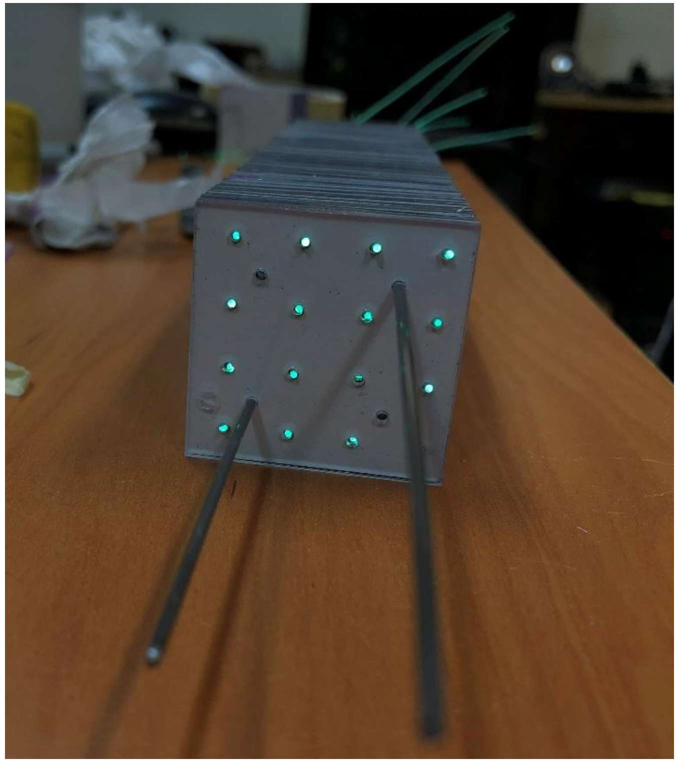
This is one important thing we want to study

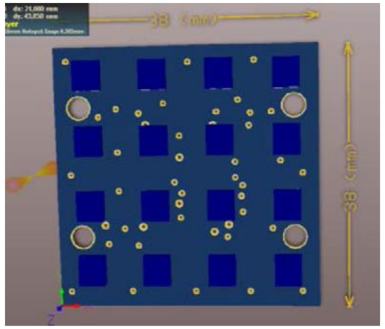
Progress on Building a W/Cu/Sci Shashlik Prototype at UTFSM

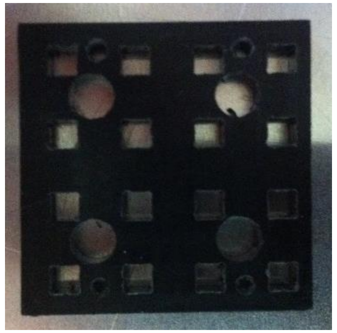
- R&D project related to NA64 at CERN funded out of internal funds at UTFSM.
- Progress has been slow due to lack of funding and local resources.
- Plan is to finish construction of first prototype module and test it in the lab. Will ultimately build 6 prototype modules.
- No funds available to purchase SiPMs. Would like to equip modules with new SiPMs and study their performance.

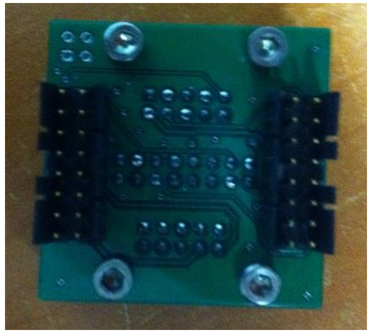
W/Cu/Sci Shashlik Prototype at UTFSM





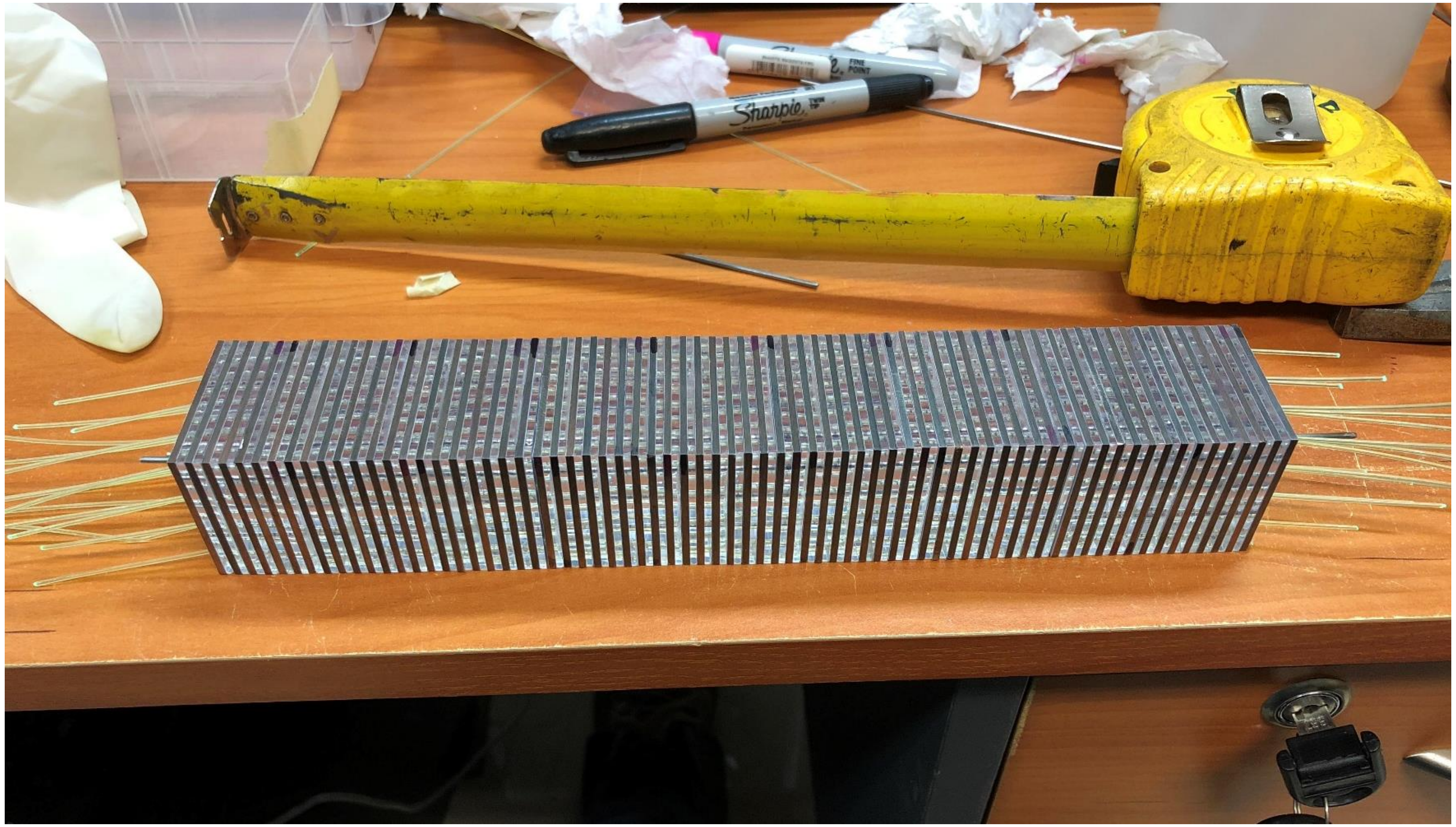






2x2 array of 19 x 19 mm^2 towers each read out with a 2x2 array of 3x3 mm^2 SiPMs

W/Cu/Sci Shashlik Prototype at UTFSM



38 x 38 x 1.5 mm W80/Cu20 absorber plates and scintillators
Total length: 20 X0

R&D Plan for FY18

- Finish building the 20 X0 shashlik module started in FY18 but not completed due to lack of funding. This will be completed at UTSFM using internal funding (except for SiPMs).
- Equip with new 3x3 mm^2 SiPMs from Hamamatsu or KETEK .
- Test with cosmic rays in the lab at UTFSM.
- Study optical readout components (scint tiles, WLS fibers, SiPMs) in the lab and using optical ray tracing program to optimize readout configuration for best uniformity of light collection and energy response (BNL).
- Study PHENIX shashlik calorimeter modules (Pb/Scint/WLS) at BNL reconfigured for individual readout of each fiber with SiPMs for comparison with a non-compact design.
- Study radiation damage (n, gammas) in new SiPMs at BNL.
- Send 20 X0 module to BNL for testing and readout with sPHENIX readout electronics.
- Build 5 or more additional modules at UTSFM.
- Test 2x3 array (minimum 24 towers) of W/Shashlik modules and a small array of PHENIX shashlik modules in the test beam at Fermilab.

Requested Budget

Full Funding

Amount ($K)	Activity
5	SiPMs
5	Misc electronic components (cables, adapter boards, etc)
15	Technical support at BNL (technician, designer)
5	Support for UTFSM at BNL for 1 month
10	Travel (includes support for UTFSM and BNL)
10	Test beam (in collaboration with sPHENIX or other EIC calorimeter test)
50	Total w/o overhead
25	Overhead
75	Total with overhead

20% Reduction

Amount ($K)	Activity
5	SiPMs
5	Misc electronic components (cables, adapter boards, etc)
15	Technical support at BNL (technician, designer)
5	Support for UTFSM at BNL for 1 month
10	Travel (includes support for UTFSM and BNL)
	Test beam (in collaboration with sPHENIX or other EIC calorimeter test)
40	Total w/o overhead
20	Overhead
60	Total with overhead

40% Reduction

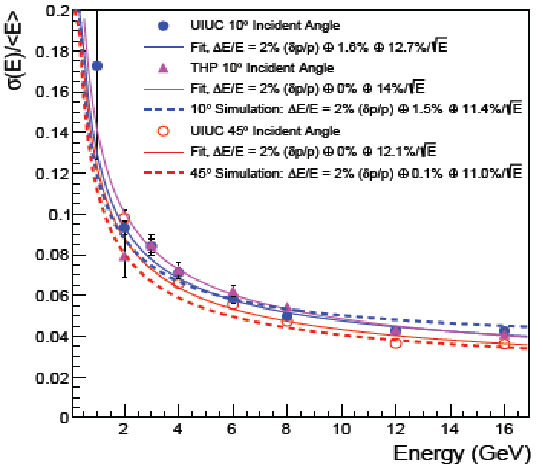
Amount ($K)	Activity
5	SiPMs
5	Misc electronic components (cables, adapter boards, etc)
10	Technical support at BNL (technician, designer)
5	Support for UTFSM at BNL for 1 month
5	Travel (includes support for UTFSM and BNL)
	Test beam (in collaboration with sPHENIX or other EIC calorimeter test)
30	Total w/o overhead
15	Overhead
45	Total with overhead

Backup

Energy Resolution

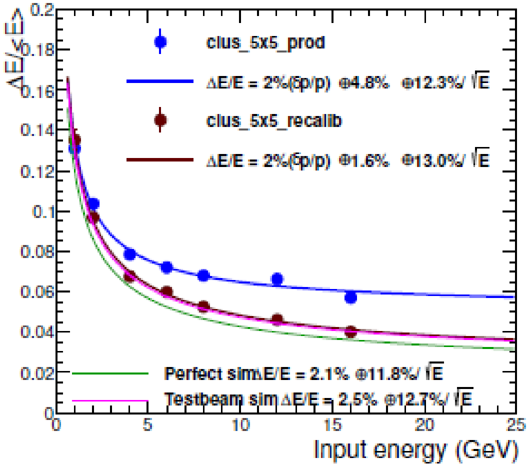
Beam Centered on a single tower

2016



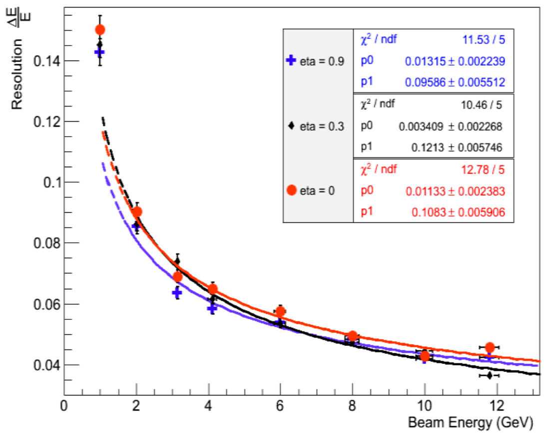
1D Projective (η = 0)

2017



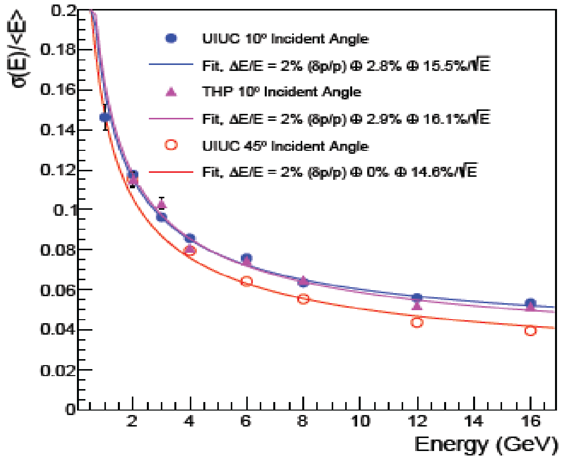
2D Projective (η ~ 0.9)

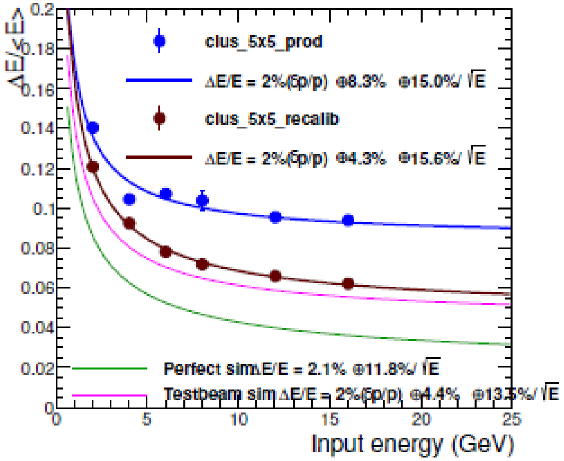
2014 - UCLA



1D Projective (η = 0, 0.3, 0.9)

O.Tsai (2014)





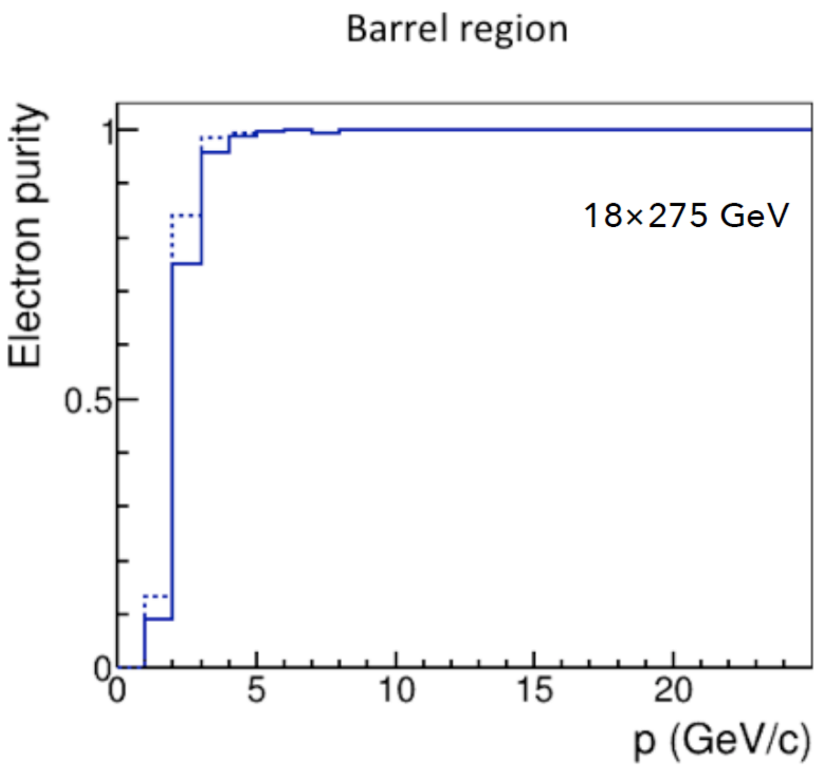
sPHENIX design spec is:

$\sigma_E/E < 16\%/\sqrt{E} \oplus 5\%$

Preliminary results from 2018 beam test with V2.1 prototype gives

$\sigma_E/E \sim 16\%/\sqrt{E} \oplus 3.2\%$

Electron Purity vs E-Resolution



Solid: $\frac{\sigma_E}{E} = \frac{16\%}{\sqrt{E}} \oplus 5\%$

Dotted: $\frac{\sigma_E}{E} = \frac{10\%}{\sqrt{E}} \oplus 1\%$

S.Bazilevsky (BNL)